PHOTOPERIODIC RESPONSE OF SOYBEANS IN RELATION TO TEMPERATURE AND OTHER ENVIRONMENTAL FACTORS[1]

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INTRODUCTION

In earlier papers[2 3] dealing with the effect of relative length of day and night on plant growth and development, considerable attention was given to the contrasted responses of early and late varieties of soybeans to changes in day length. These contrasted responses seemed to be correlated with the changes in behavior of the different varieties under field conditions with advance of the season. Of the four varieties studied under field conditions in the vicinity of Washington, D. C., the Biloxi consistently behaved as a very late variety, earliest plantings first coming into flower about September 1 and failing to mature seed; the Tokyo was somewhat earlier, the first plantings usually flowering early in August and successfully maturing seed; the Peking flowered about 10 days earlier than the Tokyo, or toward the close of July, being well adapted to the region; the Mandarin behaved as an early variety, flowering 3 to 4 weeks after germination. Thus the normal vegetative periods of early plantings of the four varieties, in the order named, are about 95, 65, 55, and 25 days, respectively.

It was found that, when early plantings of the four varieties are exposed to an artificially shortened daylight period of 10 to 12 hours or less, all varieties tend to flower at about the same time, namely, 20 to 25 days after germination. In other words, all behave as early varieties. Again, in field plantings of the four varieties made at intervals of three or four days through a single growing season, the vegetative period of plantings of the Mandarin made during the months of June and July did not change materially; while in the other varieties there was a progressive shortening of the vegetative period as the season advanced. The latest variety, Biloxi, showed the maximum shortening of the preflowering period of growth with advance of the season. Hence, in the late plantings there is, again, an evident tendency in all varieties to behave as when exposed to an artificially shortened day length in early summer. However, the duration of the vegetative period of the late plantings failed to reach the lower level of 20 to 25 days obtained with the shortened day lengths in early summer. Moreover, a considerable lengthening of the vegetative period was observed in the very early plantings of all

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[2] GARNER, W. W. and ALLARD, H. A. EFFECT OF RELATIVE LENGTH OF DAY AND NIGHT AND OTHER FACTORS OF THE ENVIRONMENT ON GROWTH AND REPRODUCTION IN PLANTS. Jour. Agr. Research 18: 553-606, illus. 1920.

[3] ——— and ALLARD, H. A. FURTHER STUDIES IN PHOTOPERIODISM, THE RESPONSE OF THE PLANT TO RELATIVE LENGTH OF DAY AND NIGHT. Jour. Agr. Research 23: 871-920, illus. 1923.

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varieties, including the Mandarin. The tentative conclusion was reached that under practical conditions in the field the differences in behavior of soybean varieties with respect to time of flowering are due primarily to length of day, while the relatively low temperatures of late spring and early fall exercise a retarding influence on the flowering stage in both the very early and the very late plantings of all varieties.

METHODS

It seemed probable that the relationships existing between the early and late forms of soybeans were more or less applicable to a large group of species of which the different forms normally flower on different dates in early and late summer and early fall. It appeared very desirable, therefore, to obtain more definite data on the interrelationship of length of day and temperature as influencing the initiation of reproductive activity in the different varieties of soybeans under natural conditions in the field. Such information should be of considerable value in arriving at a conclusion as to the actual significance of length of day as a factor in the natural distribution of plants and their adaptation to different latitudes.

For this purpose three series of experiments were carried out. In the first series, field plantings of the four varieties of soybeans were made at regular intervals of four or five days throughout the growing season at Washington for the years 1920 and 1922 to 1927, inclusive. The results in this series furnish a basis for determining the normal behavior of the different varieties with the advance of the open season in the vicinity of Washington. In the second series of tests, plantings were made in the greenhouse at regular intervals throughout the year and the mean temperature was maintained at an approximately uniform level. In the third series, beginning as early in the spring as outside conditions would permit, plantings of the soybeans were made in boxes in the greenhouse at regular intervals, and as soon as germination had taken place the plants were subjected to a fixed day length of 10 hours under approximately outdoor conditions. To accomplish this the usual arrangement of trucks on steel tracks and ventilated dark houses was employed.[4] The plants in the first series, of course, were subjected to the natural conditions of day length and temperature prevailing during the open growing season; those in the second series were exposed to the natural change in day length taking place throughout the year, but under a relatively fixed mean temperature approximating that of midsummer; the only essential difference between the treatment given in the third series and that given in the first series was that the plants in the third series were exposed to a constant day length of short duration.

EXPERIMENTAL DATA

FIELD PLANTINGS MADE AT INTERVALS THROUGH THE GROWING SEASON

The plantings were made at intervals of three to five days through the season in accordance with the plan followed in 1919, as described in the writers' first paper.[5] The tests were carried out each year from

[4] A description of the outfit used is contained in an earlier publication. See GARNER, W. W., and ALLARD, H. A. Op. cit., p. 559. (See footnote 2.)
[5] GARNER, W. W., and ALLARD, H. A. Op. cit., p. 569. (See footnote 2.)

1920 to 1927, inclusive, except in 1921. The period required for germination of the seed naturally varied somewhat, depending on prevailing weather conditions, and consequently the dates of germination did not conform rigidly to the schedule of plantings. In order to tabulate the experimental data in summarized form, the actual dates of germination were arbitrarily grouped into periods of one week each and the middle of the week was taken as the average date of germination for a group. For example, all plantings germinating during the week of May 16 to 22 are classed as having germinated on May 19. In some instances an error of one or two days for the averaged dates of germination may be involved, but the results are sufficiently accurate for practical purposes. The earliest date on which flowering had become general in each planting was noted, as was the average height attained by the plants. The results are presented in summarized form in Tables 1, 2, 3, and 4. The data previously obtained in 1919 also are included in the tables. Because of poor seed the Tokyo plantings in 1923 were largely a failure and are not included in the tables.

The average values for the 8-year period are shown graphically in Figure 1. The graph for Biloxi plantings in the greenhouse covering the same period of the year, as described under the next section, is added to facilitate comparison. The seasonal change in length of day, which of course is essentially uniform from year to year, is shown graphically in Figure 2. The average mean temperature during the vegetative period of each planting of the four varieties for the eight years was computed from the Weather Bureau records, and the values applicable to the Mandarin and Peking varieties are shown in Figure 1. The data for Tokyo and Biloxi are very nearly the same as those for Mandarin and Peking and hence are omitted. Naturally, the plantings of late June and early July experienced the highest average temperature (75° to 77° F.) for the preflowering period of growth. In considering these temperature data, as shown in Figure 1, it is to be remembered that the figures do not refer to specific calendar periods indicated in the chart but rather to the periods of time elapsing between germination and first flowering in the particular plantings indicated in each case.

The yearly fluctuations in time of flowering of plantings germinating on any given date are considerable, the extreme range being about 15 days. Also, the heights of the plants vary widely from year to year. Presumably length of day is not a significant factor in these yearly fluctuations, but irregularities in temperature and other variable factors might well account for the observed fluctuations. To afford ready comparison of the variations in length of the vegetative period of the soybeans and differences in the prevailing temperature, the detailed data for the Biloxi and Mandarin varieties, together with the mean temperatures of the vegetative periods in 1925 and 1927, are shown in Figure 3.

TABLE 1.—*Dates of germination and flowering, duration of vegetative period, and average heights of the Mandarin variety of soybeans planted at intervals of three to five days through the open growing season at the Arlington Experiment Farm, Rosslyn, Va., in the years 1919, 1920, and 1922–1927*

Average date of germination	Date of first blossoming in—								
	1919	1920	1922	1923	1924	1925	1926	1927	Average
May 19	June 16	June 25	June 17	June 17	---	June 16	June 26	June 26	June 20
May 26	June 22	June 27	June 21	June 13	June 28	June 22	June 29	June 27	June 25
June 2	June 28	June 30	June 25	June 25	July 3	June 27	July 3	July 2	June 29
June 9	July 6	July 5	July 2	July 4	July 8	July 1	July 9	July 8	July 5
June 16	July 13	July 11	July 11	July 9	July 12	July 8	July 14	July 14	July 12
June 23	July 21	July 18	July 17	July 18	July 18	July 20	July 21	July 18	July 19
June 30	July 26	July 24	July 23	July 23	July 24	July 23	July 25	July 24	July 24
July 7	July 31	July 31	July 30	Aug. 1	July 30	July 29	July 30	July 30	July 30
July 14	Aug. 7	Aug. 7	Aug. 5	Aug. 8	Aug. 7	Aug. 6	Aug. 5	Aug. 6	Aug. 6
July 21	Aug. 15	Aug. 16	Aug. 14	Aug. 12	Aug. 13	Aug. 14	Aug. 10	Aug. 14	Aug. 13
July 28	Aug. 21	Aug. 17	Aug. 21	Aug. 23	Aug. 21	Aug. 20	Aug. 17	Aug. 27	Aug. 21
Aug. 4	Aug. 28	Aug. 25	Aug. 30	Aug. 29	Aug. 26	Aug. 27	Aug. 28	Sept. 4	Aug. 29
Aug. 11	Sept. 7	Sept. 4	Sept. 5	Sept. 4	Sept. 3	Sept. 5	Sept. 4	Sept. 14	Sept. 6
Aug. 18	Sept. 11	Sept. 13	Sept. 11	Sept. 17	Sept. 16	Sept. 9	Sept. 12	Sept. 16	Sept. 13
Aug. 25	---	Sept. 25	Sept. 19	Sept. 25	Sept. 20	Sept. 16	---	Sept. 22	Sept. 21
Sept. 1	---	---	Sept. 27	Oct. 1	---	Sept. 23	Sept. 23	Oct. 4	Sept. 28

Average date of germination	Duration of vegetative period in—								
	1919	1920	1922	1923	1924	1925	1926	1927	Average
	Days	*Days*	*Days*	*Days*	*Days*	*Days*	*Days*	*Days*	*Days*
May 19	28	37	29	29	---	28	38	38	32
May 26	27	32	26	28	33	27	34	32	30
June 2	26	28	23	23	31	25	31	30	27
June 9	27	26	23	25	29	22	30	29	26
June 16	27	25	25	23	26	22	28	28	26
June 23	28	25	24	25	25	26	28	25	26
June 30	26	24	23	23	24	23	25	24	24
July 7	24	24	23	25	23	22	23	23	23
July 14	24	24	22	25	24	23	22	23	23
July 21	25	26	24	22	23	24	20	24	24
July 28	24	20	24	27	24	23	20	29	24
Aug. 4	24	21	26	25	22	24	24	31	25
Aug. 11	27	24	25	24	23	25	24	31	25
Aug. 18	24	26	24	30	29	22	25	28	26
Aug. 25	---	31	25	31	26	22	---	30	28
Sept. 1	---	---	26	30	---	22	22	33	27

Average date of germination	Average height of plants in—								
	1919	1920	1922	1923	1924	1925	1926	1927	Average
	In.	*In.*	*In.*	*In.*	*In.*	*In.*	*In.*	*In.*	*In.*
May 19	---	19	---	16	---	11	8	11	13
May 26	---	19	---	17	13	12	8	11	13
June 2	---	20	---	18	13	12	8	12	14
June 9	---	21	---	18	15	12	9	11	14
June 16	---	21	---	17	14	11	9	11	14
June 23	---	21	---	17	14	13	10	13	15
June 30	---	17	---	18	14	14	11	10	14
July 7	---	17	---	20	14	15	10	9	14
July 14	---	17	---	20	17	18	10	11	16
July 21	--	16	---	19	17	15	7	11	14
July 28	---	20	---	17	16	10	7	10	13
Aug. 4	---	19	---	15	15	9	9	9	13
Aug. 11	---	17	---	15	12	13	9	9	13
Aug. 18	---	16	---	16	10	12	9	7	12
Aug. 25	---	12	---	15	9	11	---	7	11
Sept. 1	---	---	---	14	---	9	8	7	10

TABLE 2.—*Dates of germination and flowering, duration of vegetative period, and average heights of the Peking variety of soybeans planted at intervals of three to five days during the open growing season at the Arlington Experiment Farm, Rosslyn, Va., in the years 1919, 1920, and 1922–1927*

Average date of germination	Date of first blossoming in—								
	1919	1920	1922	1923	1924	1925	1926	1927	Average
May 19	July 12	July 29	July 18	July 16	---------	July 13	July 28	July 30	July 21
May 26	July 18	July 30	July 19	July 19	July 31	July 18	do	do	July 24
June 2	July 29	Aug. 1	July 23	July 24	Aug. 1	July 23	do	do	July 28
June 9	Aug. 4	Aug. 3	July 29	July 27	Aug. 4	Aug. 1	Aug. 2	Aug. 1	Aug. 1
June 16	Aug. 7	Aug. 5	Aug. 2	Aug. 3	Aug. 7	Aug. 2	Aug. 4	Aug. 5	Aug. 4
June 23	Aug. 11	Aug. 10	Aug. 6	Aug. 10	Aug. 9	Aug. 11	Aug. 6	Aug. 9	Aug. 9
June 30	Aug. 15	Aug. 13	Aug. 10	Aug. 14	Aug. 14	Aug. 13	Aug. 10	Aug. 10	Aug. 12
July 7	Aug. 18	Aug. 18	Aug. 15	Aug. 19	Aug. 20	Aug. 18	Aug. 13	Aug. 15	Aug. 17
July 14	Aug. 21	Aug. 21	Aug. 20	Aug. 25	Aug. 26	Aug. 23	Aug. 18	Aug. 20	Aug. 22
July 21	Aug. 25	Aug. 23	Aug. 26	Aug. 28	Aug. 30	Aug. 31	Aug. 20	Aug. 29	Aug. 27
July 28	Sept. 6	Aug. 31	Sept. 3	Aug. 31	Sept. 3	Sept. 3	Aug. 30	Sept. 3	Sept. 2
Aug. 4	Sept. 7	Sept. 2	Sept. 8	Sept. 6	Sept. 4	Sept. 5	Sept. 2	Sept. 13	Sept. 6
Aug. 11	Sept. 11	Sept. 9	Sept. 11	Sept. 10	Sept. 10	Sept. 8	Sept. 9	Sept. 19	Sept. 11
Aug. 18	Sept. 18	Sept. 18	Sept. 15	Sept. 21	Sept. 17	Sept. 13	Sept. 15	Sept. 28	Sept. 18
Aug. 25	Sept. 26	Sept. 25	Sept. 22	Sept. 28	Oct. 2	Sept. 20	---------	Oct. 4	Sept. 27
Sept. 1	---------	---------	Oct. 1	Oct. 1	---------	Sept. 26	Sept. 29	Oct. 5	Sept. 30

Average date of germination	Duration of vegetative period in—									Average height of plants in—								
	1919	1920	1922	1923	1924	1925	1926	1927	Average	1919	1920	1922	1923	1924	1925	1926	1927	Average
	Days	*Days*	*Days*	*Days*	*Days*	*Days*	*Days*	*Days*	*Days*	*In.*	*In.*	*In.*	*In.*	*In.*	*In.*	*In.*	*In.*	*In.*
May 19	54	71	60	58	-----	55	70	72	63	---	31	---	30	---	25	14	20	24
May 26	53	65	54	54	66	53	63	65	59	---	30	---	30	25	27	14	20	24
June 2	57	60	51	52	60	51	56	58	56	---	32	---	32	28	26	15	22	26
June 9	56	55	50	48	56	53	54	53	53	---	36	---	33	25	21	12	20	25
June 16	52	50	47	48	52	47	49	50	49	---	38	---	32	28	22	15	17	25
June 23	49	48	44	48	47	49	44	47	47	---	35	---	30	27	21	13	15	24
June 30	46	44	41	45	45	44	41	41	43	---	33	---	30	25	23	11	15	23
July 7	42	42	39	43	44	42	37	39	41	---	31	---	27	25	22	11	13	22
July 14	38	38	37	42	43	40	35	37	39	---	28	---	26	23	20	12	13	20
July 21	35	33	36	38	40	41	30	39	37	---	27	---	26	23	17	11	11	19
July 28	40	34	37	34	36	37	33	37	36	---	26	---	21	21	19	11	9	18
Aug. 4	34	29	35	33	31	32	29	40	33	---	25	---	21	14	16	10	9	16
Aug. 11	31	29	31	30	30	28	29	39	31	---	22	---	20	12	14	9	8	14
Aug. 18	31	31	28	34	30	26	28	41	31	---	20	---	20	13	10	10	8	14
Aug. 25	32	31	28	34	38	26	-----	40	33	---	17	---	16	11	8	---	8	12
Sept. 1	-----	-----	30	30	-----	25	28	34	29	---	---	---	17	---	6	9	7	10

TABLE 3.—*Dates of germination and flowering, duration of vegetative period, and average heights of the Tokyo variety of soybeans planted at intervals of three to five days during the open growing season at the Arlington Experiment Farm, Rosslyn, Va., in the years 1919, 1920, 1922, and 1924–1927*

Average date of germination	Date of first blossoming in—									Duration of vegetative period in—									Average height of plants in—								
	1919	1920	1922	1923	1924	1925	1926	1927	Average	1919	1920	1922	1923	1924	1925	1926	1927	Average	1919	1920	1922	1923	1924	1925	1926	1927	Average
										Days	*Days*	*Days*	*Days*	*Days*	*Days*	*Days*	*Days*	*Days*	*In.*	*In.*	*In.*	*In.*	*In.*	*In.*	*In.*	*In.*	*In.*
May 19	July 29	Aug. 3	July 24	-----	-----	Aug. 3	Aug. 4	Aug. 8	Aug. 2	71	76	66	-----	-----	76	77	81	75	---	35	---	---	---	36	25	32	32
May 26	Aug. 1	do	do	-----	Aug. 11	Aug. 8	do	do	Aug. 4	67	69	59	-----	77	74	70	74	70	---	35	---	---	33	42	20	30	32
June 2	Aug. 11	Aug. 4	July 28	-----	do	Aug. 10	Aug. 7	do	Aug. 7	70	63	56	-----	70	69	66	67	66	---	36	---	---	33	42	23	28	32
June 9	Aug. 15	Aug. 9	Aug. 7	-----	Aug. 12	Aug. 13	Aug. 13	Aug. 15	Aug. 12	67	61	59	-----	64	65	65	67	64	---	40	---	---	33	36	20	28	31
June 16	Aug. 19	Aug. 11	Aug. 11	-----	Aug. 17	Aug. 16	Aug. 17	Aug. 16	Aug. 15	64	56	56	-----	62	61	62	61	60	---	42	---	---	35	29	20	27	31
June 23	Aug. 20	Aug. 16	Aug. 13	-----	Aug. 23	Aug. 22	Aug. 18	Aug. 18	Aug. 19	58	54	51	-----	61	60	58	58	57	---	40	---	---	34	27	18	22	28
June 30	Aug. 21	Aug. 19	Aug. 15	-----	Aug. 26	Aug. 25	Aug. 22	Aug. 23	Aug. 22	52	50	46	-----	57	56	53	54	53	---	37	---	---	32	28	18	20	27
July 7	Aug. 27	Aug. 22	Aug. 21	-----	Aug. 29	Aug. 30	Aug. 28	Aug. 30	Aug. 27	51	46	45	-----	53	54	52	54	51	---	36	---	---	29	24	20	17	25
July 14	Aug. 31	Aug. 29	Aug. 24	-----	Sept. 1	Sept. 2	Aug. 30	Sept. 4	Aug. 31	48	46	41	-----	49	50	47	52	48	---	33	---	---	25	29	20	16	25
July 21	Sept. 5	Aug. 31	Aug. 30	-----	Sept. 2	Sept. 7	Sept. 3	Sept. 8	Sept. 3	46	41	40	-----	43	48	44	49	44	---	32	---	---	25	27	20	15	24
July 28	Sept. 10	Sept. 3	Sept. 6	-----	Sept. 7	Sept. 8	do	Sept. 10	Sept. 7	44	37	40	-----	41	42	37	44	41	---	31	---	---	20	26	18	12	21
Aug. 4	Sept. 11	Sept. 5	Sept. 10	-----	Sept. 15	Sept. 11	Sept. 14	Sept. 17	Sept. 12	38	32	37	-----	42	38	41	44	39	---	26	---	---	17	22	19	12	19
Aug. 11	-----	Sept. 13	Sept. 13	-----	Sept. 24	Sept. 15	Sept. 22	Sept. 19	Sept. 18	-----	33	33	-----	44	35	42	39	38	---	23	---	---	16	20	19	12	18
Aug. 18	-----	Sept. 23	Sept. 20	-----	Oct. 3	Sept. 17	Sept. 25	Sept. 28	Sept. 24	-----	36	33	-----	46	30	38	41	37	---	21	---	---	14	15	17	12	19

TABLE 4.—*Dates of germination and flowering, duration of vegetative period, and average heights of the Biloxi variety of soybeans planted at intervals of three to five days during the open growing season at the Arlington Experiment Farm, Rosslyn, Va., in the years 1919, 1920, and 1922–1927*

Average date of germination	Date of first blossoming in—								
	1919	1920	1922	1923	1924	1925	1926	1927	Average
May 19	Sept. 4	Sept. 3	Sept. 4	Aug. 30	----------	Aug. 29	Sept. 1	Sept. 6	Sept. 2
May 26	Sept. 5	do	do	do	Sept. 2	Sept. 3	do	do	Sept. 3
June 2	Sept. 7	Sept. 5	do	Sept. 2	do	do	Sept. 2	do	Sept. 4
June 9	Sept. 10	Sept. 7	Sept. 7	Sept. 4	Sept. 3	Sept. 6	Sept. 3	Sept. 7	Sept. 6
June 16	Sept. 13	Sept. 9	do	Sept. 9	Sept. 9	Sept. 9	do	Sept. 11	Sept. 9
June 23	Sept. 15	Sept. 13	Sept. 9	Sept. 12	Sept. 12	Sept. 10	Sept. 7	Sept. 15	Sept. 12
June 30	Sept. 17	Sept. 15	Sept. 11	Sept. 15	Sept. 14	Sept. 12	Sept. 9	Sept. 17	Sept. 14
July 7	Sept. 18	Sept. 17	Sept. 14	Sept. 18	Sept. 19	Sept. 14	Sept. 14	Sept. 18	Sept. 17
July 14	Sept. 22	do	Sept. 15	Sept. 22	Oct. 2	Sept. 13	Sept. 18	Sept. 22	Sept. 20
July 21	Sept. 21	Sept. 21	Sept. 18	Sept. 24	Oct. 3	Sept. 19	Sept. 21	Sept. 30	Sept. 23
July 28	Sept. 29	Sept. 27	Sept. 24	Sept. 28	Oct. 6	Sept. 23	Sept. 23	Oct. 1	Sept. 28
Aug. 4	Oct. 1	Oct. 2	Sept. 29	Oct. 2	Oct. 8	do	Oct. 5	Oct. 4	Oct. 2
Aug. 11	Oct. 6	Oct. 7	Oct. 3	----------	----------	Oct. 4	Oct. 8	Oct. 6	Oct. 6
Aug. 18	Oct. 16	Oct. 19	Oct. 9	----------	----------	Oct. 7	Oct. 10	----------	Oct. 12

Average date of germination	Duration of vegetative period in—									Average height of plants in—								
	1919	1920	1922	1923	1924	1925	1926	1927	Average	1919	1920	1922	1923	1924	1925	1926	1927	Average
	Days	*Days*	*Days*	*Days*	*Days*	*Days*	*Days*	*Days*	*Days*	*In.*	*In.*	*In.*	*In.*	*In*	*In.*	*In.*	*In.*	*In.*
May 19	108	107	108	103	-----	102	105	110	106	---	50	52	51	---	36	29	36	42
May 26	102	100	101	96	99	100	98	103	100	---	50	58	51	42	36	29	39	44
June 2	97	95	94	92	92	93	92	96	94	---	51	53	50	43	36	35	40	44
June 9	93	90	90	87	86	89	86	90	89	---	53	51	50	41	34	30	39	43
June 16	89	85	83	85	85	85	79	87	85	---	53	48	50	34	35	30	34	41
June 23	84	82	78	81	81	79	76	84	81	---	53	47	48	32	36	25	28	38
June 30	79	77	73	77	76	74	71	79	76	---	50	46	44	27	35	24	25	36
July 7	73	72	69	73	74	69	69	73	72	---	47	41	39	23	32	21	22	32
July 14	70	65	63	70	80	61	66	70	68	---	40	36	36	25	29	20	18	29
July 21	62	62	59	65	74	60	62	71	64	---	36	33	34	25	27	20	17	27
July 28	63	61	57	62	70	53	56	65	61	--	33	30	31	24	25	20	16	26
Aug. 4	58	59	56	59	65	50	62	61	59	---	30	25	25	22	23	20	15	23
Aug. 11	57	58	54	-----	-----	55	59	57	57	--	25	22	22	---	19	20	12	20
Aug. 18	59	62	52	-----	-----	50	53	-----	55	---	23	21	20	---	16	20	---	20

The supply of moisture in the soil available to the plant and the relative humidity are additional factors which conceivably might affect the initiation of reproductive processes. For obvious reasons records of rainfall alone do not furnish a very satisfactory indication of available soil moisture, but for the sake of comparison the total rainfall was computed from Weather Bureau records during the period of vegetative growth of each planting of the Mandarin in 1925, 1926, and 1927, and the data are given in Table 5. Corresponding values of the computed relative humidity also are included in the table. The figures for relative humidity were obtained by averaging the

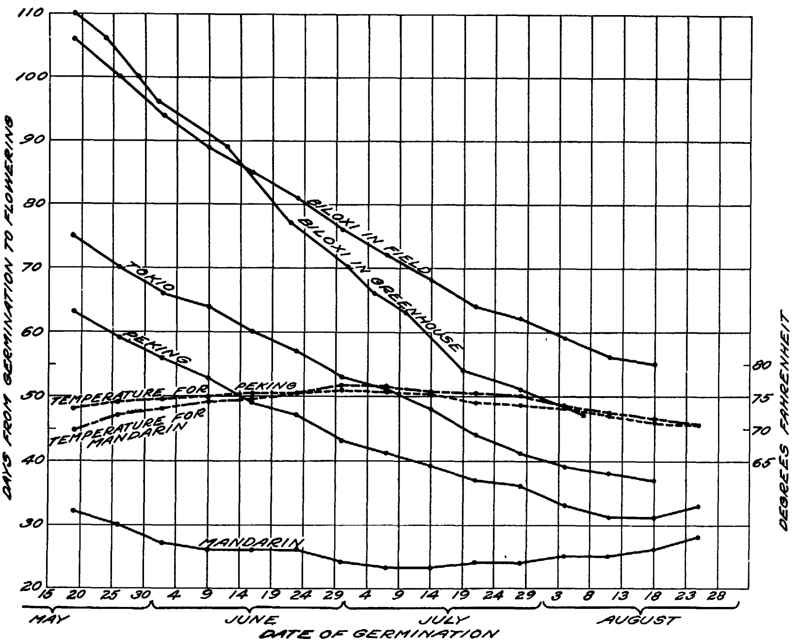

FIGURE 1.—Average number of days from germination to first flowering in field plantings at Arlington Experiment Farm, Rosslyn, Va., of early, medium, and late varieties of soybeans made at short intervals through the growing season in 1919, 1920, and 1922–1927, and in similar greenhouse plantings of the latest variety (Biloxi) in the corresponding season of 1928; also the computed average mean temperature for the vegetative period of each planting of the early (Mandarin) and medium (Peking) varieties. In all except the earliest variety there is a progressive shortening of the vegetative period with advance of season, the maximum effect occurring in the latest variety, Biloxi (see text p. 731)

observations made daily at 8 a. m., noon, and 8 p. m. by the Weather Bureau.

GREENHOUSE PLANTINGS MADE AT INTERVALS THROUGH THE YEAR

Beginning June 18, plantings of Mandarin, Peking, and Biloxi soybeans were made in the greenhouse at intervals of three to five days. The experiment was continued till the middle of August in the following year, a period of about 14 months. An effort was made to maintain an approximately constant mean temperature as far as conditions would permit, but there was no control of the humidity. Facilities were not available for automatic control of the temperature, but it was possible to secure fairly satisfactory results, particularly during

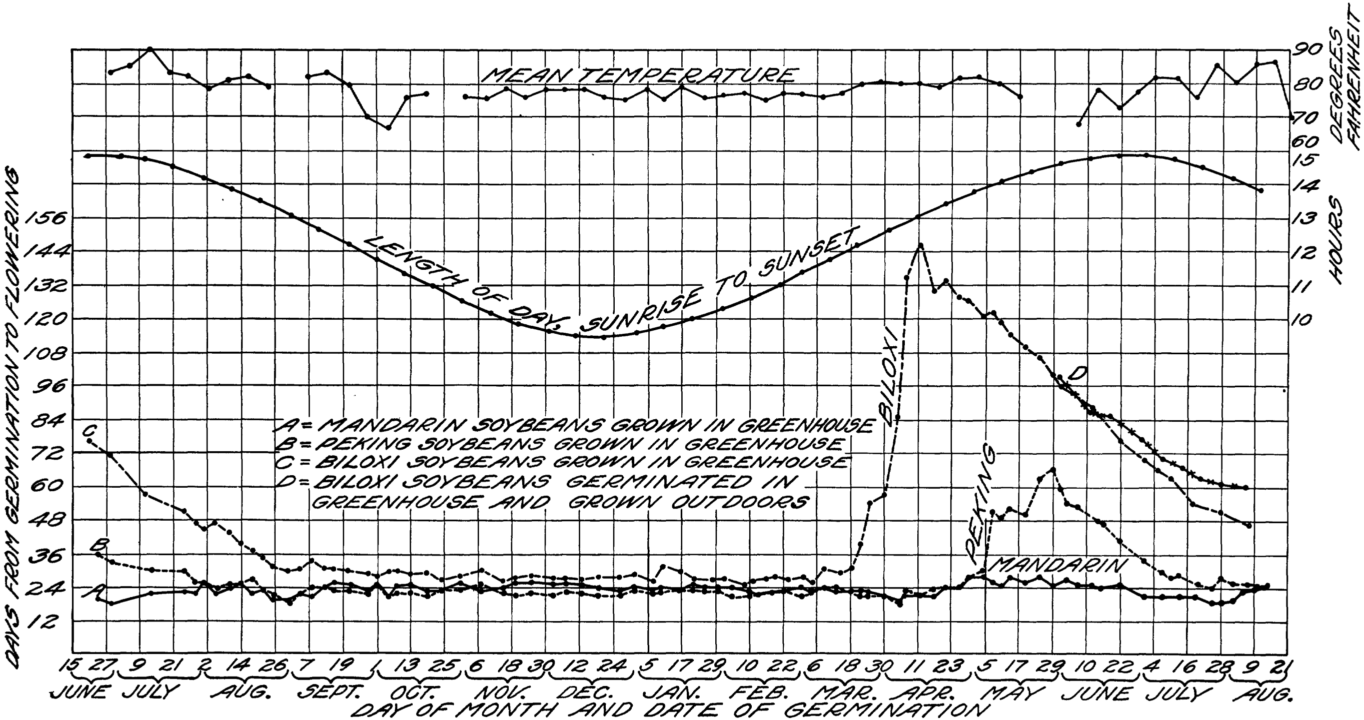

FIGURE 2.—Number of days from germination to first flowering in greenhouse plantings of early, medium, and late varieties of soybeans made at frequent intervals through the year; also the mean weekly temperature in the greenhouse and the seasonal change in length of day. With a favorable, comparatively constant temperature the vegetative period of all varieties was about the same during the fall, winter, and early spring, when the days were short. Later in the spring the increasing day length showed a marked selective action on the different varieties, and only the early variety continued to flower during the longest days of summer (see text, p. 731)

the late fall, winter, and early spring, by hand control of heating and ventilation. Unfortunately, three of the weekly temperature records were lost. In general, the temperature level was close to the mean midsummer temperature at Washington.

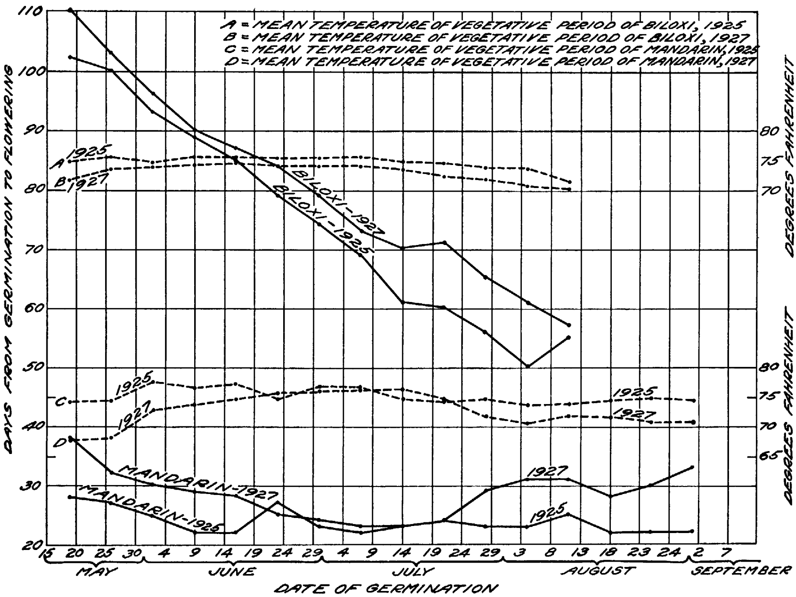

FIGURE 3.—Number of days from germination to first flowering in the successive plantings of the earliest (Mandarin) and the latest (Biloxi) varieties of soybeans in 1925 and 1927; also the computed mean temperature during the vegetative period of each planting of the two varieties. Earlier flowering in 1925 as compared with 1927 in all plantings, except those of the Mandarin made in midsummer, seems to be definitely correlated with the relatively high temperature prevailing in 1925 (see text, p. 730)

TABLE 5.—*Mean relative humidity and total rainfall during the preflowering stage of growth in successive field plantings of Mandarin soybeans at Washington, D. C., in 1925, 1926, and 1927*

Average date of germination	Mean relative humidity in—			Total rainfall in—		
	1925	1926	1927	1925	1926	1927
	Per cent	*Per cent*	*Per cent*	*Inches*	*Inches*	*Inches*
May 19	56	59	68	0.77	1.62	3.26
May 26	59	60	68	1.22	1.73	3.98
June 2	59	61	66	1.51	1.38	3.98
June 9	59	64	65	1.90	2.56	4.09
June 16	63	64	68	2.61	2.41	2.47
June 23	66	64	67	2.46	3.53	5.10
June 30	64	66	70	1.86	4.01	1.18
July 7	65	65	70	3.36	2.52	1.48
July 14	65	69	70	2.92	2.13	2.05
July 21	67	69	68	5.42	1.34	1.33
July 28	67	75	71	3.85	4.72	3.42
August 4	67	76	72	3.24	5.18	4.18
August 11	66	79	73	2.52	8.57	3.16

The results with respect to duration of the vegetative period obtained with each variety are shown by means of graphs in Figure 2. The mean weekly temperatures in the greenhouse and the annual range in day length, sunrise to sunset, are likewise shown in the form of graphs. To facilitate comparison the results with Biloxi for the period of the year corresponding to that of the field plantings are plotted in part also in Figure 3.

In connection with the above tests, plantings of the Biloxi were made in boxes in the greenhouse at intervals, beginning May 27, and after germination had taken place the boxes were placed out of doors. The time required for each planting to reach the flowering stage, as compared with the results in the greenhouse, is shown in Figure 2, D.

PLANTINGS THROUGH THE OPEN GROWING SEASON EXPOSED TO A 10-HOUR DAY

Beginning April 20, plantings of the Peking and Biloxi varieties were made at intervals of three to five days in large boxes in the greenhouse. After germination the boxes were placed on trucks which were daily wheeled out of doors early in the morning and 10 hours later returned to ventilated dark houses having temperatures approximating those prevailing outdoors. In this way the soybeans were

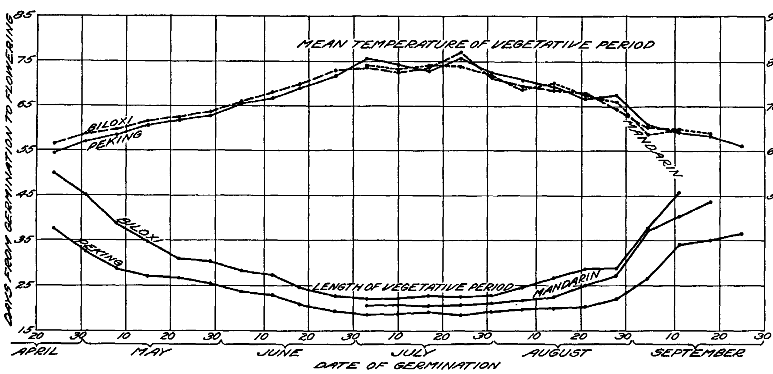

FIGURE 4.—Number of days from germination to first flowering in successive plantings of the Mandarin Peking, and Biloxi varieties of soybeans which were exposed to approximately outdoor conditions of temperature and a fixed day length of 10 hours. The midsummer temperature appears to be near the optimum for flowering in all varieties, and the lower temperatures of late spring and early fall cause a considerable delay in flowering. There seems to be little indication of a selective action of temperature on the early and late varieties

exposed to a fixed day length of 10 hours but were subjected to essentially outdoor conditions of temperature. Beginning July 1, similar plantings of the Mandarin variety were included in the test. The results as to time required for each variety to reach the flowering stage are shown graphically in Figure 4, which also shows in each instance the computed mean temperature of the vegetative period of plants.

The Weather Bureau records indicate that for the most part the seasonal weather conditions in the year of the test (1928) were fairly close to normal, especially with respect to temperature. The mean temperature for August, however, was 2 degrees above normal and that of September 3 degrees below normal. Except in July the relative humidity averaged somewhat above normal. The rainfall was below normal in June and July but extraordinarily heavy in August and above normal in September. On the whole the weather conditions seem to have been such as to give a very good picture of the average seasonal effect of temperature on soybeans when the factor of length of day is inoperative.

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DISCUSSION OF RESULTS

As a basis for interpreting the results obtained in the present series of experiments, it may be regarded as established that the Mandarin, Peking, Tokyo, and Biloxi varieties of soybeans, which range in behavior from very early to very late flowering types when grown in the field in the vicinity of Washington, D. C., all flower in midsummer within a period of 20 to 25 days after germination, if exposed to an artificially shortened day length. In other words, when exposed to a warm summer temperature and a short day, all behave as early varieties. It has been observed also that when grown in a warm greenhouse in the winter months, when the days are naturally short, these varieties show the same behavior. It has been shown in an earlier paper, moreover, that the soybean is a warmth-loving type, with the result that a cool temperature tends to delay flowering. This fact has been further brought out by Eaton [6] and by Gilbert.[7]

In the successive plantings in the field through the season, covering a period of eight years (Tables 1, 2, 3, 4, and fig. 1), there are two features of the growth relations which are of interest: (1) Variations from year to year in growth and in date of flowering of plantings germinating on any given date; (2) a general trend toward reduced growth in all varieties and shortening of the vegetative period in all varieties except the Mandarin as the date of germination is advanced. Despite the rather wide variations from year to year, the general trends with advance of season are clearly evident in each year of the test. With respect to the yearly fluctuations, the results in the years 1925 and 1927 (fig. 3) serve to bring out the significance of variation in temperature as a causal factor. In the Biloxi the vegetative period was longer in 1927 than in 1925 throughout the season. In the Mandarin the same difference occurs except in the midsummer plantings. In both cases there is obviously a close correlation between the differences in mean temperature and the differences in length of the preflowering growth period in the two years. Under the conditions of the experiment, temperature seems to be the dominant factor in the yearly fluctuations in time of flowering. The indications are that sustained temperatures below the midsummer average of about 75° to 77° F. will ordinarily tend to cause a delay in flowering. Moreover, it appears that, under the conditions, a decrease of 1° in the mean temperature of the vegetative period causes a delay of some two or three days in date of flowering.

A comparison of the computed mean relative humidity and the total rainfall during the vegetative period of each of the Mandarin plantings in 1925, 1926, and 1927 (Table 5) with the duration of the period of vegetative activity (Table 1) fails to show any consistent correlation. For example, the longer vegetative period of the 1927 plantings germinating prior to June 23, as compared with the 1925 data, is associated with a higher humidity and increased rainfall. When the 1926 data are included in the comparison, however, it is seen that in all plantings germinating prior to June 23 the dates of flowering in 1926 and 1927 agree closely and are considerably later than in 1925, whereas the humidity records and in large part the

[6] EATON, F. M. ASSIMILATION-RESPIRATION BALANCE AS RELATED TO LENGTH OF DAY REACTIONS OF SOYBEANS. Bot. Gaz. 77: 311-321, illus. 1924.

[7] GILBERT, B. E. THE RESPONSE OF CERTAIN PHOTOPERIODIC PLANTS TO DIFFERING TEMPERATURE AND HUMIDITY. Ann. Bot. [London] 40: 315-320, illus. 1926.

rainfall data for 1926 agree rather closely with those of 1925 but not with those of 1927. Again, during the latter part of the summer the relative humidity was much higher in 1926 than in 1925, but there was no decided difference in the duration of the vegetative period in the soybeans.

A comparison of the average growth rates of the soybeans in 1925 and 1927 shows decided differences except in the earlier germinations of the Mandarin and Biloxi (Tables 1–4), and the relative heights attained by the plants were much reduced in 1927. On the whole, correlation of differences in height of the plants with temperature differences is not consistently maintained, indicating that other potent factors also are operative. As an illustration, it will be noted that the materially lower temperature prevailing in 1927 during the growing period of early plantings of the Mandarin and Biloxi (fig. 3) failed to retard the growth as compared with results in 1925. Considering the average results for the eight years, it is evident that the final heights attained are greatest in the early plantings.

Obviously, the irregularities, or fluctuations, in duration of the vegetative phase of growth at any given period of the year will tend to disappear when average results over a period of years are considered. As a consequence, the graphs showing the changes in duration of the vegetative phase in the different varieties with advance of season (fig. 1) become relatively smooth, thus presenting very clearly defined trends. In this case, in relation to date of flowering, we presumably have, besides the day-length factor, the effect of a relatively uniform seasonal trend in temperature, instead of the more or less sharply fluctuating temperature conditions likely to occur in any single year. In all except the very early variety of soybeans the effects of temperature and length of day on late spring and early summer plantings apparently are additive, both the rising temperature and the decreasing day length favoring earlier flowering with advance of season. In midsummer the average temperature seems to be near the optimum, and only the length of day acts as a major limiting factor. As soon after midsummer as the average temperature begins to fall the two factors of day length and temperature become opposed, the former tending to hasten flowering and the latter to delay it. With the very early variety, Mandarin, neither day length nor temperature is an important limiting factor in misdummer, while in spring and early fall temperature is the only primary factor.

The above-stated considerations relate primarily to the behavior of the different varieties, considered individually. It is of special interest, however, to determine to what extent the sharp contrasts in behavior with respect to earliness shown by the different varieties are really due to the factors of day length and temperature. Under field conditions at Washington these varietal distinctions are always clearly apparent despite irregularities in actual time of flowering induced by temperature fluctuations. The greenhouse plantings through the year furnish a clear picture of the relative effects of day length on the duration of the vegetative period of the different varieties at different seasons of the year when the obscuring effects of varying temperature are largely removed. (Fig. 2.) During the 6-month period in which the day length is about 12 hours or less, the distinction between the varieties with respect to earliness is almost entirely lost, a fact which is in accord with conclusions reached in the earlier work. However, as has been previously observed, the minimum duration of the vegetative phase in Biloxi consistently remained slightly greater than for Mandarin and Peking.

Beginning about March 20, the increasing day length seems to have brought about a rather sudden change in the behavior of the Biloxi. The duration of the vegetative phase of growth increased rapidly till, in the plantings germinating April 4 and shortly thereafter, individual plants in increasing numbers remained in the vegetative stage throughout the summer and till the return of short days in the early fall. After April 17 all individuals in each planting remained in the vegetative stage till fall and for a time the successive plantings tended to flower on the same date. This behavior of the Biloxi with advance of season results in a graph of characteristic form. (Fig. 2.)

A word of caution may not be out of place here relative to the interpretation to be placed upon the portion of the graph showing the lengthening of the vegetative period in the plantings after March 20. It is not to be inferred that these plantings attained the flowering stage in the indicated number of days as a direct result of exposure to the long days of late spring and early summer. On the contrary, it should be understood that flowering was initiated in these plantings only when the excessively long days had shortened to the required point in late summer. There is nothing to indicate how long vegetative activity would have continued if the longest days of summer had remained in effect for a prolonged period. The comparatively uniform decrease in duration of the vegetative period in successive plantings following the planting that germinated April 12 is due to the fact that all the plants began to flower as soon as a fairly definite decrease in day length had taken place. Available information indicates that this occurred early in August.

Beginning about May 8, after the day length had further increased, the Peking practically duplicated the change in behavior shown earlier by the Biloxi except that the change in duration of the vegetative stage of development was somewhat less abrupt and of less magnitude. As in the case of the Biloxi, the distinctive form of this portion of the graph (fig. 2) indicates response to a definite decrease in day length. In contrast with the Biloxi and the Peking, the Mandarin showed no significant change in duration of the vegetative stage at any time during the spring and summer. It is clear that the annual cycle of day length exercises a distinctly selective action on the different varieties of soybeans. Moreover, with respect to earliness in flowering, the relative positions of the three varieties under comparatively constant conditions of temperature remained the same during the period of late spring and summer as in the field plantings previously considered. During the remainder of the year all behaved as early varieties, as previously stated, the preflowering stage of growth being only from 20 to 30 days.

A direct comparison of the behavior of the Biloxi in the greenhouse and in the field is made in Figure 3. It is apparent that in the later plantings the shortening of the vegetative period is less rapid in the field than in the greenhouse, and the explanation probably is to be found in the higher temperature level in the greenhouse. Further evidence of the retarding action of suboptimum temperature on date of flowering is furnished by the Biloxi plantings made in the greenhouse and transferred to outdoor conditions of temperature after germination. (Fig. 2, D.)

It remains to consider the effects of change in temperature with advance of season when the length of day is held constant. (Fig. 4.) The fixed day length of 10 hours which was employed is approximately the optimum for flowering in each of the three varieties. As the maximum mean temperature of the vegetative stage of growth is approached in the midsummer plantings, the duration of the vegetative stage attains the minimum value of 18 to 22 days. The generally convex form of the temperature curves constitutes a close counterpart of the concave form of the curves representing the duration of the vegetative period. Evidently there is a definite correlation of temperature with the duration of the vegetative stage. There is, however, no suggestion of the sort of varietal distinction in behavior with advance of season that was associated with the annual cycle in length of day under conditions of constant temperature. Though the evidence is not conclusive, there is some indication that the lower temperatures of late spring and early fall exert a somewhat selective, retarding action on attainment of the flowering stage as between the Mandarin and Biloxi, on the one hand, and the Peking on the other hand. However, the earliest variety, Mandarin, and the latest variety, Biloxi, seemingly respond in much the same way to changes in temperature; and there is no indication of selective action of this factor on these two varieties of soybeans.

So far as may be inferred from the foregoing data, differences in temperature do not account for the differences in behavior of soybean varieties. Seasonal change in length of day exercises a decided selective action on the different varieties and may well constitute the controlling external factor in the differences in time required by the several varieties to attain the flowering stage when grown under similar conditions. The annual range in length of day in the latitude of Washington, from about 9½ to 15 hours, is not sufficient to affect greatly the time of flowering in the very early variety, Mandarin. It is probable, however, that in higher latitudes having a maximum day length of, say, 16 hours or more, this variety would tend to behave about as the Peking does at Washington; that is, the date of flowering would be delayed by the longest days of summer.

In so far as the relationships existing between the early and late forms of soybeans are applicable to the different forms of other warmth-loving species which normally flower in early and late summer and early fall, it appears that the length-of-day factor may exercise a dominant influence on the relative adaptation of these early and late forms to a given latitude. As the sensibility to lower temperature increases, the more essential it becomes that the plant be able to initiate reproductive processes in response to changes in day length occurring comparatively early in the season, if the plant is to reproduce itself successfully in any given region outside the Tropics. This apparently would tend to enable the plant to escape the destructive action of cold. In this connection it may be noted that the progress of the seasonal change in length of day keeps well in advance of the corresponding stage in the seasonal temperature change. Thus, in the latitude of Washington the maximum and the minimum day lengths of the year occur about a month in advance of the maximum and the minimum mean temperatures. It seems logical to suppose that, in contrast with the interrelationship of temperature and length of day as regards effects on warmth-loving species like soybeans, the drop in temperature as summer gives way to fall will serve to aid the decreasing length of day in hastening the attainment of the reproductive stage in short-day plants of the cool-loving type.

SUMMARY

In this paper consideration is given to the comparative behavior of early, medium, and late varieties of soybeans, more particularly with respect to duration of the purely vegetative stage of development when planted at frequent intervals through the growing season and when grown under partially controlled conditions. When planted early in the season in the vicinity of Washington, D. C., these varieties, known as Mandarin, Peking, Tokyo, and Biloxi, normally require about 25, 55, 65, and 95 days, respectively, for attaining the flowering stage. All varieties are quite sensitive to cool temperatures.

Data were obtained on field plantings made at intervals through the growing season over a period of eight years. The time of flowering of plantings of a given date varied considerably from year to year, and these variations seem to be closely correlated with yearly fluctuations in the prevailing temperature. Definite correlation of fluctuations in date of flowering with differences in relative humidity and rainfall could not be traced, although these factors may not be entirely without effect on the results. Despite the yearly fluctuations, very definite trends as to change in duration of the vegetative stage with advance of the season can be seen in each variety, all except the Mandarin showing progressive shortening of the vegetative stage. The mean midsummer temperature at Washington (75° to 77° F.) appears to be approximately optimum for all varieties and the suboptimum temperatures of spring and late summer tend to delay flowering in the very early and very late plantings.

In plantings of Mandarin, Peking, and Biloxi made in the greenhouse through the year, with a fairly constant mean temperature approximating that of midsummer, there was a period of about six months in which all three varieties reached the flowering stage in about 25 days after germination and, therefore, behaved as early varieties. During this period the length of day ranged approximately from 9½ to 12 hours and it is evident that the short days showed no selective action on the different varieties. Late in March, however, when the day length had increased further, the late-flowering variety, Biloxi, suddenly began to lengthen its period of vegetative growth until a maximum of 146 days was reached or until there was a return to short days in early fall. Beginning about six weeks later in the spring, the Peking experienced the same sort of lengthening of the period of vegetative growth, although the change was less pronounced. The Mandarin showed no decided change in duration of the vegetative phase of development. Thus the increasing length of day exercised a distinct selective action on the three varieties of soybeans, and the contrasts in behavior of these varieties were essentially the same as those obtained in the field. In general, in the later plantings, the progressive shortening of the vegetative period with advance of season was somewhat less pronounced in the field than in the greenhouse, presumably because of the retarding action of the lower

temperature out of doors. Moreover, plantings transferred at germination from the greenhouse to outdoor temperatures showed a delay in flowering.

In plantings of the three varieties made at intervals through the growing season and exposed to a fixed day length of 10 hours, there was apparently a rather close correlation of the length of the preflowering stage of growth with the mean temperature. In each variety the minimum vegetative period corresponded to the highest mean temperature of midsummer, with appreciable delays in time of flowering associated with the lower temperatures of late spring and early fall. Apparently the lower temperatures affected the earliest variety, Mandarin, and the latest variety, Biloxi, in much the same way, there being no evidence of a definite selective action of the changing temperature on the two varieties.

The available evidence seems to indicate that under field conditions at Washington variations from year to year in date of flowering of both early and late varieties of soybeans when planted on any particular date are due chiefly to differences in temperature, while length of day is the primary external factor responsible for the fact that one variety is always relatively early and another late in attaining the reproductive stage. It seems likely that the relationships existing between the early and late forms of soybeans will apply equally to many other species, although it does not follow, of course, that the differences in behavior of early and late varieties of all species are explainable on the basis of the length-of-day factor.

The variation in growth rate from year to year in the different varieties, which may be quite marked, seems to be due in part to temperature fluctuations and in part to other environmental factors. Over a period of years the average heights attained by the earlier plantings as a rule markedly exceed those attained by later plantings.